REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY): 01-04-2004

2. REPORT TYPE: Final Report

3. DATES COVERED: July 1, 1995 - Sept 30, 1999

4. TITLE AND SUBTITLE: A Study on the Relationships between Anthropogenic sounds, whale sounds, and behavior and physiology of free-swimming whales

5a. CONTRACT NUMBER: N00014-95-1-1181, Code 251: KES

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S): Dr. Jeffrey Goodyear

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): University of British Columbia, Department of Zoology, 6270 University Blvd, Vancouver, BC V6T 1Z4, Canada

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES): Office of Naval Research, 800 N. Quincy Street, Arlington, VA 22217-5000

10. SPONSOR/MONITOR'S ACRONYM(S): ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AILABILITY STATEMENT: Distribution Unlimited

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

See summary of project in the attached report.

15. SUBJECT TERMS

20040413 031

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclass	Unclass	Unclass	UL	12	Dr. Jeffrey Goodyear
					19b. TELEPHONE NUMBER (Include area code): 250-381-9425

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Final Report Submitted to:

Office of Naval Research

ONR Grant#: N00014-95-1-1181, Code 251:KES

A STUDY ON THE RELATIONSHIPS BETWEEN ANTHROPOGENIC SOUNDS, WHALE SOUNDS, AND BEHAVIOR AND PHYSIOLOGY OF FREE-SWIMMING WHALES

Jeffrey Goodyear
UBC Account: 5-54811
University of British Columbia
Department of Zoology
6270 University Blvd.
Vancouver, British Columbia
Canada V6T 1Z4
Phone/FAX (250)381-9425
e-mail: jgoody@islandnet.com

ONR Program Officer: Dr. Robert Gisiner

Long-Term Research Objective: To study the relationships of anthropogenic sounds to specific aspects of whale behavior and physiology. Further, how low frequency sounds might negatively affect these parameters and habitat-use patterns.

Science and Technology Objectives: Refine and apply multi-sensor radio/satellite telemetry/data logging tags (MST-VHF and MST-SAT tags developed under a previous ONR grant) to free-swimming whales and use them as the key tools to test for and evaluate specific affects of anthropogenic sound sources.

Summary of Approach: The MST-VHF and MST-SAT tags record one or several of the following parameters which are then downloaded directly by serial cable or via telemetry: heart rate, speed, roll, yaw, depth, sound, temperature, and others. Extent and rate of change in one or more of these parameters of a tagged whale were to be compared under "control"--no anthropogenic sounds, and "test" conditions--anthropogenic noise present e.g. from ships, research sources, fisheries, and others. Repeatable-measured patterns of change in response to characterized sounds simultaneously recorded using gear aboard independent platforms nearby would provide evidence that whales are affected by certain anthropogenic sounds. Negative affects would be interpreted as directly observed departures from associated sound stimuli and/or statistically significant shifts in the activity budget of animals compared with the normal or control condition.

SUMMARY OF PROJECT

This report summarizes general activities and achievements made under ONR grant N00014-95-1-1181 of ONR's low-frequency sound initiative. The project, referred to here as "Phase II" commenced in 1995 and ran through September 1998 (including a 1 year no-cost extension). Phase II is inextricably tied with activity under ONR grant N00014-92-J-1613 (1992 through 1995 with no-cost extension) referred to here as "Phase I" which focused primarily on development of technology as used in Phase II. Therefore, some discussion of Phase I will be included.

The primary objectives of Phase II were to test and refine whale tag systems developed in Phase I, and apply them in field studies to measure the potential affects of low-frequency sounds on large whales. Specifically, the research applications were to monitor selected behavioral, physiological, and movement parameters principally of right and humpback whales in "control situations"--areas with minimal or no human marine activity (e.g. fishing, shipping, blasting etc.)--and in areas where there were consistent shipping, fisheries, Naval, and other human marine activities which produce underwater sounds. If the whale tag systems were found to be effective tools in this project's planned field research, then they would be made available to outside studies in areas where Naval and civilian acoustic activities were occurring to enable testing for long-term impacts.

The basic principal of the research effort was simple. However, its execution was complex and difficult to achieve. The first of the two principal objectives was successfully achieved. Significant advances and refinement in

instrumentation and methodology beyond the Phase I project resulted in tag systems capable of addressing the primary Phase II objective of impact assessment. These developments are expected to serve as valuable tools to the rest of the scientific community in ongoing research assessing potential impact of anthropogenic sounds on whales. Similarly, they will provide detailed behavioral and physiological data for general scientific study unobtainable through other means.

The objective of assessing impact potential of anthropogenic sounds on whales was elusive. Despite a highly intensive field effort, only some of the proposed field plans were achieved and no impact-related data were obtained. Unusually poor weather and ecological conditions plagued several field seasons while a serious crash of our field vehicle terminated our 1996 Alaska field effort. Importantly, given the urgency of the assessment objectives in this study, the interest to complete them remains undiminished. It is the full intent of the PI to apply the technology in independent and collaborative field efforts in the future toward these objectives. As implied above, much of the technology developed in this research has already been disseminated and used in a variety of other projects assessing human impacts on whales and for collecting ecological information on free-swimming whales; many others are being planned. Since the end of the grant period, the technology has been made available to other researchers through a commercial outlet[1].

The remainder of this report briefly describes the technological developments. The effort, scope, and results of the independent field projects are briefly summarized. The efficacy of the project and future plans are discussed in general.

TECHNOLOGICAL ACHIEVEMENTS

MST-VHF tags: multi-sensor data logging and telemetering radio tags:

In order to identify and assess affects of anthropogenic sounds on free-swimming whales per ONR's LF (low frequency) initiative, I originally proposed that the best chances of success involved direct measurement of several parameters at the whale. A complex, very small, completely autonomous multi-sensing recording and telemetering tag system would be needed. Phase I prototype tags were developed and are referred to as "MST-VHF" (multi-sensor telemetering VHF radio) and "MST-SAT" (satellite linked version). The present grant expanded on and refined these tags for practical use in impact studies for free-swimming whales of interest to ONR.

These tags are approximately 3cm x 3cm x 10cm with an additional 5cm x 5cm x 10 cm of flotation depending on number of sensors selected in each tag. The basic components of the tag are a data logger capable of sampling a wide variety of parameters, a transmitter to telemeter portions or all of the data, an effective attachment and deployment system, and a pressure/waterproof housing. Parameters sampled, recorded, and telemetered include several or all of the following in a single tag: 1) speed; 2) heart rate; 3) temperature; 4) body orientation in 1 to 3 planes (roll, pitch, yaw); 5) depth of dive; 6) surfacing time; 7) dive time; 8) dive duration; 9) seawater salinity; 10) light level; and 11) sound recording. Non-acoustic data were sampled and stored at a rate from 1 to 240 seconds until memory was full (up to 1 megabyte; memory space could be much larger with increase in tag size). Two software and hardware versions of the acoustic sampling system were devised; see "Sensor" section.

VHF Transmitter and Telemetry Decoder:

Near the end of the Phase I grant, wildlife radio transmitters available from existing telemetry companies were deemed inadequate for effectively telemetering data from MST tags. Furthermore, despite the wildlife telemetry industry's use of the term "telemetry", receivers capable of reliably receiving and decoding telemetered data, aside from simple trackable audio beeps, were unavailable. To achieve the project goals, we first developed a very small highly versatile high-output telemetry transmitter and encoding software appropriate for the MST tag systems. In turn, we took off the shelf "telemetry" receivers and designed the appropriate decoding circuitry. Field tests near the end of Phase I revealed that much more work was needed to make the available receivers effective for functional telemetry. The present project made significant advances on the transmitters and add-on decoder circuits for the receivers. This project succeeded in increasing the effective telemetering baud rate from approximately 50 with an effective range of approximately 1 km, to a baud rate of about 300 and a range of 3 to 8 km. These advances vastly improved the practicality of the MST telemetering function enabling substantial tracking/monitoring distances from the tagged whales for the impact studies.

MST-Sat tags: multi-sensor data logging and telemetering Argos satellite tags:

"MST-Sat" tags are very similar to the MST-VHF tags described above. The principal hardware difference is that they contain an Argos satellite transmitter to enable global tracking and data recovery not requiring direct

[1] H.A.B.I.T. Research, Ltd. is a research and manufacturing company established in December 1998 specializing in telemetry systems for marine and terrestrial wildlife. Details on whale and other tag systems are available on website www.habitresearch.com.

tracking. The key application of MST-Sat tags in this project was to project long-term--up to several months--of data from whales far out of reach of direct radio tracking. In other words, data and location of whales could be obtained during their extensive migration e.g., on humpbacks traveling from Alaska to Hawaii. These tags were to provide more generalized data given that the Argos system can only accommodate a very low data telemetry rate, approximately 32 bytes of data per transmission spaced a minimum of 40 seconds apart. Therefore, data from MST-Sat tags would be most useful for detecting broader impact trends and for identifying potential impacts far offshore where the direct radio tracking/monitoring efforts were impractical.

Because Argos has such slow data rate capabilities, the tag's data sampling rate must be similarly set very slow and the sampling scheme highly organized. Typically, a large whale would surface 2 to 6 times per surfacing sequence which occurred approximately 3 to 6 times per hour. Given the Argos requirement that the "repetition rate"--the rate of data transmission--be no shorter than 40 seconds, prioritization of parameters to be sampled and number of samples was critical. Instead of recording many sequential values of a particular parameter, averaging of variables and pre-summarizing data by categorization into "bins" was optimal. For example, considering dive depth, data were summarized into maximum, mean, and median values and into a series of depth ranges, 0-5 meters, >5 to 25, >25 to 100 meters etc. Counts of values within each of these later categories were then recorded and telemetered. Of course, this approach, and therefore, the use of Argos, was impractical for measurement of some parameters, e.g. sound.

Several software-driven sampling protocols were written and lab-tested. The fact that the sampling protocols are software-driven provides great flexibility for expansion or modification if they are needed e.g. if a project changes its data requirements. MST-VHF and MST-Sat tags each serve a key role and together would provide the most effective tools for conducting impacts studies on any far-ranging animals.

Remote Radio Release:

Remote activation to initiate release of tags from whales was considered important to optimize data recovery from data recording tags. This was especially important since the Phase I telemetering system was slow and unreliable over long distances thus risking that few data would be recovered from the tag if it could not be recovered for direct serial download. Also, because the MST tags were very complex, and therefore, timely and costly to build, it made sense to recover and reuse them. In Phase I, a remote release was designed utilizing a commercially available hobby-craft radio control system. In field trials, these revealed poor range and reliability. In Phase II, a small and reliable receiver and a variety of release servo systems were designed into the MST tags. In conjunction with commercially available radio control transmitters, the new release system was reliable over several hundred meters of range, appropriate for release of MST tags from whales.

Sensors:

Of the many parameters sampled by MST tags, several sensors e.g. pressure (depth), were commercially available. However, several sensors were designed from scratch in order to accommodate specific voltage/current consumption, physical size, and/or performance requirements for the autonomous tag systems. Sensor development required design of both hardware and software. Only those developed or modified in this ONR study will be described.

Speed:

Swimming speed change was assumed to be a significant indicator of response of a whale to external stimuli. A rugged (to withstand crossbow deployment of tags) simple, small and energy-efficient sensor was needed which was unlikely to be fouled by debris in the seawater. Such a sensor was devised using a simple metal flap and "Hall Effect" transistor. Opposing magnets--one on the flap, and one internally casted in the MST tag--act as a spring with no moving parts to force the flap outwards to a zero flow point. As the whale moves forward, waterflow pressure forces the flap down. As speed increases, the flap magnet is forced closer to the Hall Effect transistor producing an increasing voltage change detectable and recorded in the tag. The flap system's small size, simplicity, and unlikely fouling give it advantages over commercially available impellor devices. This is a patentable device which could be applied in speed measurements in any liquid or gas application.

Acoustic Sensor Systems:

Several acoustic sensing and recording systems were developed. A piezo-electric element was modified to form a highly efficient and sensitive microphone encased inside the solidly casted tags. The microphone and associated circuit hardware/software sampled at 2000 Hz to cover all expected anthropogenic sources from ship's propellers, engine and machinery noise, and the ATOC (acoustic thermometry of ocean climate) project sound sources. This range would not effectively sample the upper frequencies produced by large whales themselves. However, this would cover the most prevalent frequencies they produced and critically, would allow distinction of those

frequencies of whale sounds which potentially overlap with the anthropogenic sounds. An accelerometer served as another audio sensor in particular to detect the lowest frequencies, especially <100 Hz.

Two acoustic sampling schemes were devised for the above sensors to allow for constant ambient sound recording and short "snippit" sound recordings. During tag setup--via a personal computer--a user menu allows selection for either constant sound sampling or sampling for X seconds with Y seconds interval between successive sampling periods. The snippit method is to conserve memory, battery power, and allow for minimal tag size, yet allow recording of enough acoustic data so associations of anthropogenic sounds can be made with whale behaviors.

Another acoustic system was devised which includes low, band, and high-pass acoustic filtering. This system with the band-pass focused around 72 Hz, was to provide a tool to specifically address ONR's principal sound source frequency for the ATOC project. Sounds of 72 Hz (+-8 Hz at -3db) would be recorded with time as "events". This approach minimizes the amount of memory needed so as to allow an autonomous tag to operate for several days or weeks before data needs to be downloaded. Also, given that the telemetering system can only transmit a few tens or hundreds of bytes of data per surfacing sequence, the recording of "events" vs. raw data allows a greater proportion of potential whale response events to be conveyed by telemetry.

This acoustic sampling system also has a sound level "threshold" detector. Once triggered, the 2000 Hz sampling rate would run for X seconds (settable at the user's menu). The purpose of the sound snippits was to allow characterization of incoming sounds outside of the band pass range. The threshold-based snippit system also maximized power efficiency and optimized use of tag memory for long-term response studies on tagged animals.

A simple acoustic recording system using an off-the-shelf DAT (digital audio tape) recorder was designed, but not built. Such a system would have provided exceptional quality sound recording of the whale and anthropogenic sounds. However, tag size would have been over 3X and weight about 4X that of the MST designs described above. Furthermore, such a system, would allow for only a few hours of recording and placed significant constraints on achieving the ultimate goal of assessment of impact of anthropogenic sounds on free-swimming whales. The DAT system would additionally require a separate data logger/sampling system for the other parameters necessary for detecting whale responses. The MST systems optimize the recording of the many parameters in a small and power-efficient package rugged enough to be deployed onto free-swimming whales with a crossbow or pole.

Heart Rate:

Heart rate is an important indicator of an animal's relative metabolic activity and therefore, a parameter from which an animal's response to anthropogenic sounds can be quantified. One electronic and one acoustic method of sensing heart rate were developed and incorporated into MST tags. A variety of electronic probes to detect electrical signals from the heart were developed and incorporated into the dart or suction cup attachment systems of the MST tags. In the case of dart attachments, the dart itself was wired to the tag's internal amplifier. In the suction cup mounts, the cup housed a "floating" disk that pressed against the epidermis when applied. The objective is that a positive voltage associated with each full cycling of the heart muscle represents a heart beat. Averaging time of recorded pulses is user settable at time of tag set up to provide practical interpretation of heart beat; e.g. ., heart rate averaged, e.g. over 10 second intervals likely is appropriate for a large whale's inherently low resting heart rate (approximately 30 bpm).

A second system for use in the MST tags uses either an accelerometer or piezo-electric device as a microphone to listen for the heart beat. In MST tags, the spring action keeping the tag firmly attached to a whale also keeps the sensor firmly pressed face down against the skin. This system was devised as an alternative to the electrical detection method. It is possible that non-heart muscle electrical output of the whale would mask detection of heart muscle electrical output making this acoustic system more effective. The acoustic system did detect heart beat of a captive beluga whale after a series of tests and modifications. It is likely that further adjustment would be required when used on free-swimming wild whales.

ECG:

In Phase I, a human Holter monitor was modified to obtain high sampling rate ECG recordings from whales. The PI worked with the Holter monitor manufacturer (Marquette Industries) to make hardware and software changes to these devices to better detect the presumed lower electrical signal levels arriving from the heart to the surface blubber of a whale where probes could be placed. In Phase I, the early prototype unit recorded what is believed to be the first ECG from a whale with a completely autonomous device; i.e. no cables running from the whale. That measurement was on a captive beluga whale swimming freely in a large aquarium. In Phase II, these units were reduced in size and further modified for remote deployment onto free-swimming wild whales. The purpose of these tags was two-fold.

The high sampling rates up to 240/sec would allow for detailed scrutiny of heart function when a whale was exposed to external sound stimuli. Recording times of over 24 hours were possible with these tags at its lower sampling rates--e.g. 30/sec. This rate is low for human applications, but would likely provide significant detail of the QRS complex of large whales given their inherently low resting heart rate.

Secondly, it was important to make detailed recordings of heart function as a reference point for interpreting the more crudely sampled heart rate using the methods described above. The methods used in the MST tags assumed high stability and regularity in electrical output of the resting whale heart. In other words, brief aberrations or spikes in the actual heart function could be missed when effectively low sampling rates are used. Results from the ECG tag would potentially provide insight for making adjustments to the less detailed heart rate data and for optimizing sampling protocols used in the MST tags.

Surface Detection and Salinity:

Accurate and rapid detection of the sea surface is critical for assessing surfacing and diving parameters of the whale in these response studies. A reliable sensor system largely software driven and based on sea water conductivity was designed into the MST tags. In field tests, a "comparator" approach was found to be much more reliable than one based on an absolute conductivity. For example, some of the MST tags developed in the Phase I project were applied to fin whales in the St. Lawrence Estuary where seawater salinity ranged from 0.005 to 0.035. In setting up those initial tags, an absolute threshold value was selected so that when a whale surfaced, the surfacing /dive sampling protocol and telemetering functions were initiated. However, this set threshold value did not work well across all salinities experienced by the whale. In Phase II, the system was modified so that each successive conductivity value was compared relative to a 5 second average. When submerged and ranging across the broad salinity ranges the whales were exposed to, salinity and therefore, conductivity changed only several percent over a much broader time frame of 15 seconds or more. When a whale surfaces and exposes the tag to the air, there is a salinity/conductivity change of many tens of percent in a fraction of a second. This system was extremely effective in detecting surfacing times. In addition, this system enabled absolute conductivity, and therefore salinity, to be measured, a parameter of significance to the associated habitat analysis. Futhermore, the surface detector controlled the initiation and termination of the data telemetry sequence and tracking beeps.

Oceanography/Habitat:

The basic conductivity/salinity sensor system developed in Phase I was further elaborated on in the Phase II to allow detection of haloclines. These modifications were entirely software driven. Similarly, software was written for the temperature sensor to enable detection of thermoclines. Detection of thermoclines, haloclines and other temperature and or salinity features could aid significantly in both the response studies and habitat analysis. In the response analysis, "normal" behavior must be distinguishable from that influenced by anthropogenic sources. It is possible that subtle changes in subsurface behavior could be associated with disturbance. Furthermore, assessment of the potential impact on the success of whales to feed and find prey can be aided by identifying changes in the oceanographic regime where whales are found. Consistent shift of residency or use of sub-optimal habitat due to responses could have negative impact on the whales. Knowing the oceanographic regime is important to such assessment.

Attachment and Deployment Systems:

Prior to the Phase I ONR grant, the PI had developed a wide variety of attachment and deployment systems for whale tags. Phase I placed a large emphasis on further development of these systems to achieve tag attachment times up to several months with MST type tags; see final report for grant N00014-92-J-1613. These were further elaborated on in the present grant. Of particular note, a 16 tine cam-actuated dart system was designed with the goal of providing attachment times exceeding 6 months for satellite tag systems. Although not field tested within this grant period, this system is expected to be the most successful for long-term tag attachment of MST-type tags to whales.

LAB TESTING

All devices developed under the Phase I and Phase II grants were tested in laboratory settings, on small whales in aquaria, and/or large whales at sea. In Phase II, only basic functional tests of the heart rate tags were achievable given restraints on access time and the allowable degree of manipulation of the animals. All Phase II aquarium tests were conducted on beluga whales at the Vancouver Aquarium in British Columbia. As with many institutions, the Vancouver facility was phasing out its captive killer whale program and due to public pressure, was extremely cautious about any real or perceived manipulation of remaining animals. This caution persisted despite the fact that no invasive or long-term tests of any kind were planned or attempted on the captive animals. Consequently, most

calibration of sensor systems and full-function tests of tag systems required application on free-swimming whales in the wild.

It is recommended for future research requiring access to cetacea in aquaria that agreements with several facilities be arranged and a significant proportion of the funds be budgeted for such testing. In Phase I, the project had access to the only two facilities in the region; in Phase II, only one facility was available. Facility policy, composition of training staff, and available animals, were found to change much more frequently than expected. Consequently, relatively little of the planned in-aquaria testing was conducted.

SUMMARY OF FIELD TESTING AND RESEARCH

Field Projects

Three primary studies were proposed for Phase II. Each had the common objectives to identify behavioral, physiological, and movement parameters of large whales under two conditions: 1) time or areas of consistent exposure to sounds from human activities; and 2) "control" times or areas of quiet. The primary methodology would be the same in each study. The following are brief summaries of the study areas, field activities, and results if any.

Bay of Fundy

Description

Field research on right whales (Eubalaena glacialis) was conducted in the Bay of Fundy in 1996 and 1998. Right whales routinely frequent the Bay of Fundy August through October each year primarily for feeding and nursery activities. All age and size classes, and both males and females are found there. Many commercial activities including fishing, shipping, high-speed ferry, and whale watching, expose calf and adult right whales--many other species as well--to high levels of sound and to potential risks of being directly hit by vessels. Most importantly, the primary shipping lane in the Bay bisects the area of highest concentration of right whales . This area of the bay is their most important North Atlantic feeding ground.

This studies' primary intent was to characterize the diel patterns, levels, and types of sounds and test for associations with activities of right whales simultaneously observed and with data logged and telemetered from tags on the whales. Several tags were to have been applied which contained a variety of sensors (described below).

Technology Applied

MST-VHF and location-only Argos satellite linked tags were prepared for the 1996 and 1998 Bay of Fundy research. Due to abbreviated field seasons in both years caused principally by severe weather (e.g. a series of hurricanes in 1996) no satellite tags were deployed. Two types of MST-VHF tags were prepared for the field.

One MST-VHF tag used in the Bay of Fundy recorded the whale's speed, ambient light level, body roll angle, dive depth, water temperature, surfacing time, dive duration, and heart rate using the acoustic sensor. A second MST tag had in addition to the above parameters, a complex sound recording protocol. One section of the sound recorder recorded broad-band frequencies from single Hz to 500 Hz with a 2kHz sampling rate. The second section consisted of a low, band, and high pass filter and sound-level threshold detector which turned the recorder on at ~80db (re 1 μ Pascal). Sounds above the 80 db level were recorded as "events" based on a sampling schedule selected by the user at time of tag set up; i.e. a different sampling schedule could be selected depending on the overall recording time desired.

The "data bin" approach was used because the memory capacity on board the tag was limited to 1 megabyte in this particular tag. Had the actual sound been recorded for some portion of a second or multiple seconds in each filtered frequency segment, the memory would have been filled within minutes. Furthermore, the broad band recording section of the tag which utilized a separate memory bank, was designed to record segments of sound in a user-selected schedule (input at time of tag set up as with the band-pass system) which would have allowed sound frequency and level characterization to be determined once data were retrieved. The recording protocol allowed the number of samples or "sampling points" to be recorded and the inter-sampling time to be set. For example, to maximize the use of the memory and to also be able to characterize frequency of incoming sounds below 500 Hz (e.g. from a ship's propeller, fishing gear winch etc.) a sampling protocol of 200 sampling points interspaced by 5 to 15 seconds would be sufficient to crudely describe sounds >100hz<500. Persistent or building sounds would effectively be sampled using such a protocol, but sudden unrepeated sound bursts could be missed. However, this protocol was targeted at vessels passing by, approaching, or departing areas with whales. In such situations, ship engine sounds, e.g., would progressively build or decrease overtime as boat-whale distances changed and thus would be "captured" by the broad-band recorder. The protocol could be set up to target lower frequencies and sampling schedules such as 500 sampling points interspaced by 15 to 30 seconds

would be more appropriate. The field plan was to apply this type of tag on many whales and use a range of protocols so as to collect data which would describe as well as possible, single to 500 Hz frequencies.

Field Effort

In 1996, within an approximately 2 week field time from aboard the 33' sloop "Crow", only three tagging attempts were possible, resulting in two successful attachments of MST-VHF tags on right whales. After an initial observation period, an MST-VHF tag which recorded dive depth, light level, surfacing time, speed, temperature, roll angle and heart rate (via an acoustic pick-up) was shot onto an adult right whale. Immediately after being tagged, the whale rapidly left the area to beyond telemetering range and eventually went out of radio tracking range. Some whale dive depth, light level, surfacing time, speed, temperature and roll angle data were retrieved via the telemetering link. Because the whale had traveled so far so fast, we only received sporadic distant signals and could not relocate it. About twenty five hours later, we again detected signals and retrieved the floating tag. The tag had detached from the whale via a passive magnesium release. The full data set was serially downloaded to a field computer which included all the above mentioned parameters except heart rate. Because the tag had attached to the whale with its anchor at a sharp angle, the acoustic sensor for monitoring heart rate, located on the bottom of the tag, had not coupled properly with the whale's back and did not detect or record the heart rate.

The second tagging, of an adult right whale was with an MST-VHF tag with the complex sound recording system with threshold detection. We radio tracked and received telemetered data from that whale for less than an hour before yielding to a threatening weather report and returning to port. A hurricane, followed by a week of near gale-force winds and heavy rains, limited our tracking success of the whale from land, but some signals were received indicating that the tag was still attached to the whale. The tag was still telemetering data and the whale was ranging between about 10 and 40 km offshore. On about the eighth day after tagging, high winds continued to prevent work on the sea, but we were able to conduct an aerial tracking survey. We relocated the whale approximately where we had determined it to be from the land tracking effort, approximately 10km offshore and about 20km south of the tagging site. The tag was still transmitting well, but our limited flight time precluded retrieval of data via the telemetering link.

From inside the aircraft, we attempted to activate the tag's release using the remote radio release system. Apparently, the plane's metal skin blocked the radio signal and the tag failed to release. Even if it had, we could not get out on the water to retrieve it. Two more hurricanes developed and entered the study area in succession and prevented our return to sea. Continuing high winds and foul weather were forecasted for the following two weeks which forced us to terminate the field season. The tag from the second tagging was never recovered , therefore, the data were never retrieved.

Data and Results

The tag design and crossbow deployment system in general worked very well especially considering the large size and weight of the MST-VHF tags with the stated options. Both tags flew well and their anchors fully penetrated on impact leaving each tag in an effective position for transmission.

From the first tagging, enough data were telemetered to assess the effectiveness of the telemetering system. Effective telemetering range during this tracking was approximately 2 km. Too few data were telemetered for any practical analyses of the behavior or movements of the animal. Several hours of dive depth, light level, surfacing time, speed, temperature, and roll angle data were recovered by direct serial download of the tag on recovery. Although these data were useful for general background information on right whales, the whale's departure from the immediate study area prevented us from obtaining the necessary observation and sound data with which to compare them. Also, heart rate was not recorded due the lack of coupling of the audio pick up with the whale's back. As this was our first tagging of the season and first with this size and complexity of tag, we were not discouraged by the minimal success.

Tag two attached very well and continued to transmit for at least eight days until we could no longer attempt monitoring. That it remained attached, was impressive given the particularly large size of the acoustic sampling MST tags and the small attachment dart used. It was clear that the tag was also still telemetering data. Although our shore tracking position 10 to 40 km away from the whale's position was too far for the receiver's decoder to read the data, we continued to hear the "data squeal" during most of our tracking attempts. A data squeal is produced during the first four surfacings after a long dive and consists of the recorded data stream being transmitted.

The only data collected from this tag were those telemetered just following tagging and the general surfacing and dive pattern information gleaned from the standard tracking beeps and data squeals. As with the first tagging, the appropriate data from tags, whale observations, and ambient sound recordings were not obtained for the intended comparisons to make the impact assessments.

Areas for Improvement in the Technology

Data logging tags such as the MST-VHF tags, given the electronic technology available at the time of development, inherently are too large to be fully implantable in a whale. By design, the main body of the tag must remain outside of the skin surface with the attachment anchor penetrating the external blubber. Suction attached tags do remain external in their entirety, but are known to have far shorter attachment times relative to dart attachments and were therefore not chosen for the two field applications discussed here. This imposes design constraints for both pole and crossbow deployment methods which limit the distances from which whales can be successfully tagged. Tagging by pole requires that approaches be within approximately five meters. This can be achieved routinely from some types of vessels e.g. sailboats and kayaks, under some very restricted conditions of weather and whale behavior. Further miniaturization of the electronics should lead to significant improvement in tag deployment distances achievable and to greater attachment times once tags are on whales.

Under reasonable weather conditions e.g., winds less than 18 knots and seas <1 meter, the tag systems as described can provide extensive data returns. Given the unfortunate conditions experienced in this field effort, the conditions were not adequate. Improvements in the data telemetering rate and distance would significantly improve field success. There are many cases, as in this study, when shore monitoring is the only option. Telemetering ranges exceeding 15 km would likely have provided 1 full day of data and eight days of data from the two tags respectively.

Since the project's completion, significant improvements in the telemetering system used in this study have been made by the PI and associates. The most critical component was the recent development of a state-of-the-art telemetry receiver specifically designed for reliable data telemetry. In conjunction with the present MST tags, this receiver is capable of effective decoding rates of telemetered data up to 1200 baud. Preliminary field tests suggest that reliable telemetering distances might exceed 15km.

Massachusetts Right Whales Winter/Spring 1997

Description

Field work was planned for the early arrival of right whales in Cape Cod Bay/Stellwagen Bank area of Massachusetts for February through April 1997. The objectives were as stated for the Bay of Fundy projects, but with emphasis on "controls". As right whales first return to Northern waters after the presumed winter fast, they first spend time in the Cape Cod Bay area to take advantage of high density concentrations of copepods. At this time, all vessel traffic in the vicinity of right whale areas is at its annual minimum; many days can go by where no vessels will venture into areas with right whales. This is the best time to establish control studies where minimal disturbance by anthropogenic sounds would be expected.

The field effort was piggy-backed onto another collaborative project with the Center for Coastal Studies and supported by the Massachusetts Environmental Trust and National Marine Fisheries Service. The collaborative role was to use simple "capsule" (small dart) radio tags and MST-VHF tags to ground-truth aerial and ship-board right whale survey techniques and to identify right whale movements in areas of heavy vessel and fisheries activity. Emphasis was placed on minimizing potential disturbance from our own research vessel requiring the greatest distances possible to still allow visual observation of general whale behavior. Additionally, monitoring was to be done from drifting vessels to minimize noise and affects on the whales that might potentially influence research results.

Technology Applied

The collaborative effort was separated into days for application and monitoring of MST-VHF tags and other days for simple capsule radio tags. This separation was implemented for two reasons: 1) the MST tags require closer tracking distances in order to receive telemetered data; and 2) the field effort had to accommodate the similar, but separate objectives of our collaboration. The MST-VHF tags had the same features as those used in the Bay of Fundy; see above for details.

Field Effort

During my involvement in the collaborative study from February 21 through April 10, winds consistently exceeding 70 knots that limited field time to about five days. Unusually low numbers of right whales came to the area and no opportunities materialized for application of the MST-VHF tags. The one tagging opportunity in the entire effort resulted in a right whale tagged with a simple VHF capsule tag.

Data and Results

No data recording tags were applied, therefore, no data pertinent to the ONR objective were obtained. Of note, however, an aerial survey one day following the capsule tag deployment indicated the tagged right whale had

traveled approximately 30 km to the north beyond our practical study range using the research vessels. Surveys of the study area revealed no other right whales.

Areas for Improvement in the Technology

N.A.

Massachusetts Humpbacks, Summer 1998:

Description

Field logistics for a full research effort were planned for and initiated in the Bay of Fundy in mid-August 1998. Two weeks of field cruises yielded sightings of a total of four right whales. At the end of this time, a hurricane followed by significant affects of an offshore tropical storm, hit the Bay of Fundy area. To salvage the field season, an unplanned departure was made to conduct similar research on humpback whales off Massachusetts. We sailed our 36' wooden cutter and crew south loosing several field days of actual work. The focus in Massachusetts was the same as for the Bay of Fundy except the change of species and the types of vessels producing underwater sounds.

The commercial whale watching effort off Massachusetts, especially in the Stellwagen Bank area, was very intensive. Frequently, several large power vessels could be seen approaching or near singles or groups of whales despite stringent regulations of whale-boat distances. Unlike the Bay of Fundy, routine passing of huge container ships, tankers, and fishing trawlers etc. occurred several miles away from the primary humpback feeding areas. Therefore, whale watching boats represented the closest underwater sound sources near whales.

Technology Applied

Two MST-VHF tags which included speed, depth, temperature, surface detection, roll angle, heart rate (measured electronically), light level, and sound recording were prepared for the field effort. These units also had the latest design of remote radio release incorporating our own design of release receiver.

Field Effort

As indicated in the Bay of Fundy section, our research vessel "Mary Perkins" only reached 4.5 knots under engine power and was very slow maneuvering and slow accelerating except under significant winds. Consequently, it was very difficult to approach within tagging distance of humpbacks. There was unexpected difficulty in approaching whales exacerbated by the particularly intensive whale watching activities. My qualitative assessment having conducted research in that area on humpbacks since 1980, was that the humpbacks were the most skittish and unapproachable I had ever seen.

In our only approach to within tagging distance, the whale rapidly arched and turned away. Not risking missing the opportunity, the MST-VHF tag was aggressively slammed down onto the whale resulting in damage to the tag's attachment mechanism and inversion of the tag on the whale; it attached solidly, but remained upside down. Consequently, the transmitting antenna was upside down and pressing flat against the whale's back nearly eliminating its signal. This reduced tracking distances to only a few hundred meters and at dark, we lost the whale. In efforts over the next several days, we never received more signals and did not recover the tag; no data were retrieved.

As with the Bay of Fundy effort, the key field task was to get the tag onto the whale successfully then, and only then, is it of value to apply the full field protocol including ambient sound recording from the research vessel. Therefore, the ambient recordings were not implemented.

After several more days of approach attempts using the "Mary Perkins", we switched to a 28 foot diesel powered converted fishing boat skippered by one of the prominent whale field researchers from that area. Two days of approach attempts were fruitless with no approach getting us closer than about 25 meters. I again switched to another operator and vessel, a 24 foot with center console powered by a 200 HP outboard. The operator had extensive experience in approaching whales for general observations but limited experience for tagging. Five additional approaches were achieved but no tags were deployed.

Data and Results

N. A.

Areas for Improvement in the Technology

During attachment of the one MST-VHF tag, the humpback was aggressively trying to avoid the boat. In desperation, we made the attempt anyway since we consistently had problems getting close to whales. In rushed

situations, the time available to properly position the tagging pole or aim the crossbow is minimal. To compensate for this in pole attempts, the pole must be swung into place much more rapidly which reduces control of the placement and can significantly increase the down-pressure when applying the tag. In the one tagging, this action was so forceful that it sheared off the anodized aluminum pin on the tagging pole which held the tag. This sharply bent the universal joint which held the anchor to the front end of the tag upside down. The tag remained in this position as long as we could see the whale and resulted in poor signal range.

Given the rushed circumstances, it was difficult to fault the system design. The attachment and pivot mechanisms were robust and had never resulted in this particular problem in earlier nor subsequent taggings. However, had the pin on the pole been of solid stainless steel instead of anodized aluminum tubing, the tagging might have been successful. This pin has been replaced by a solid stainless steel shaft in subsequent assemblies.

The key problems encountered in this field effort related to the unusually high vessel traffic and skittish behavior of the whales. When whales can be approached close enough for tagging (5 to 10 meters depending on tag design and deployment method) only by rushing or charging in, undue stress is put on everyone involved including the whale. Permits and laws generally don't provision for such problems. The accuracy and security of tag placements are compromised, some time to the extent that expensive and critical research gear is damaged or lost and no data are obtainable. Common to essentially all study areas I have worked in are ever-growing problems with increasing boat traffic. In most cases, field seasons are selected on the basis of residency, migration, and behavior patterns of the whales. Therefore, adjusting field seasons to times when vessel traffic is reduced and less problematic isn't often a solution to achieving effective research access to whales.

Further size reduction in MST-type tags will help achieve greater attachment success. Lighter weight and streamlining will allow for faster flying tags and greater shooting distances by use of crossbow. Increased travel velocity results in greater accuracy and therefore, success in achieving ideal attachment positions on top of the whale.

Greater shooting range is usually advantageous, however, there is a critical distance of about 10 meters (depending on height of vessel used), beyond which the angle to the whale's back is too low. The ideal position of a tag on top of a whale can only be achieved from close distances. The greater the distance, the greater the chances of hitting the whale's side. Side or low shots usually result in poor signal range and poor attachment longevity especially for larger heavier tags.

Lighter weight tags can be held and applied using longer-lighter weight poles thus greater attachment distances can be achieved. All tags developed and prepared for this study were nearly their minimal size given their capabilities. Significant advances have been made by the PI since this study which will make significant improvements in attainable deployment range of MST type tags.

Other than the technology, the most significant steps which can be taken to maximize field success are:1) select the appropriate vessel for the species and expected sea conditions as carefully as possible; 2) be prepared with in-field system modification capability to "custom fit" a particular tagging effort to the conditions; 3) make research gear as robust as possible; 4) select the field season which will maximize ability to approach whales in their most accommodating behavior if seasonality is not critical to the study; 5) effectively mark any equipment with return address etc. to maximize your chance of getting lost gear back, especially gear which might contain data; 6) before field activities, establish an awareness network about the project so that other people or groups can provide additional observations which might benefit the project and also, might be on the alert to relocate lost gear.

Alaska

Description

Field activities on humpback whales were planned for the Frederick Sound area of southeast Alaska for October and November, 1996, and 1997. The objectives were the same as for the Bay of Fundy right whale study with some exceptions. The field conditions were best suited to be able to establish control situations for use of the sound recording MST-VHF tags and for the ambient sound recordings. In the Frederick Sound/Petersburg area, there are many passages, coves, and other waterways where humpbacks congregate in significant numbers every fall and where human activity of any kind is rare. This characteristic was expected to provide the best possibility and flexibility for the comparative research of whales exposed to or isolated from human sound sources. The hope therefore, was to tag whales in both settings--both within the scope of our logistical capability--and be able to monitor tagged individuals while they spent time in both conditions. In such conditions, behavioral, physiological, and movement responses to anthropogenic sound could best be identified from the "normal" condition.

Technology Applied

Two MST-VHF tags were prepared for the field effort which included: speed, depth, temperature, surface detection, body roll angle, heart rate (measured acoustically), light level, and sound recording. These units also had the latest design of remote radio release incorporating our own design of release receiver. I also prepared three Argos satellite-linked tags, two MST-SAT tags which telemeter depth, and a capsule type dart tag which provided location only. I was prepared with both crossbow and pole deployment systems for all tags.

Field Effort

While driving in northern British Columbia on the way to beginning our 1996 field effort in Alaska, one of my field assistants flipped and totaled my field vehicle. Equipment damage, direct losses, logistical delays and extra expenses caused by the accident eliminated our chances for conducting that field effort; we had to return home.

In our 1997 Alaskan effort, we arrived in Petersburg, and conducted field work late October through early December. We encountered approximately three humpbacks per day on average, which was far fewer than experienced by researchers there in past years. The 28 foot diesel-powered aluminum vessel "Eclipse" was reliable, but very noisy underwater. We attempted in excess of 50 approaches using this vessel and got within marginal crossbow tagging distance (about 10 meters) on only three occasions; tagging with poles would not have been possible. Slow, fast or drifting approaches made little difference to our success. On approximately 20 approaches using a two person ocean kayak, we got no closer than about 35 meters, too far for deploying tags.

Two MST-VHF tags were shot from marginal distances, and did not attach. One simple capsule satellite tag was successfully deployed in the northwestern Frederick Sound area.

Data and Results

The one satellite tag deployed provided locations of the tagged whale for eight days indicating it remained in the general area for that period. Aside from this "sample" of data, no data were collected relating to the principal objectives.

To comment on the general lack of tagging success in the Alaska study, it was likely not significantly related to the vessels used since whales were even wary of our approaches from the kayak at great distances. Most likely, it related to the late start to the field season when humpbacks were extremely active and on the move. The prominent whale activity appeared to be pre-migration harassment by individual males of single adult females or females with calves. The males literally chased other lone whales--presumably females in most cases--rarely slowing or stopping at the surface. Few patches of macro-zooplankton or schooling fish were seen on the sonar surveys which is consistent with the fact that we observed no bubble feeding formations during our entire field period. Therefore, no stationary groups of whales were seen. In past work in southeast Alaska which always occurred earlier in the fall, locating large groups of feeding whales and achieving tagging success was very easy. I had made the decision to select this region of Alaska based on my past successes there and on recent information provided by several regional researchers. Stoichasticity prevailed, resulting in minimal field success.

Areas for Improvement in the Technology

As in the Bay of Fundy work, too few opportunities to apply the technology were achieved to be able to assess it. In the three approaches which did result in a tag being shot, shooting distances were very marginal even for the one satellite capsule tag shot. One MST tag was shot from approximately 10 meters in near darkness, a desperate attempt at best. The second MST was shot in a very aggressive rush verging on "unacceptable" given research permit restrictions. The vessel and whale movements were too extreme, and the MST tag missed the dorsum of the whale as it accelerated its arch to dive.

Increasing the power of the compound crossbow beyond the 225 pounds would be very unlikely to improve tagging success for some of the reasons discussed in the Massachusetts field section. As also discussed above, tag size reduction will improve field success. However, the simple fact remains that working at sea even given the best made plans, can not adjust or compensate for the weather and sea conditions, or for ecological or biological conditions which might cause shifts in whale distributions or behaviors. Field plans for Alaska were made well in advance. In planning, both my experience and that of other researchers there indicated that my selection of field time should have been ideal from the perspective of the whale's behavior, their approachability, and their numbers. My recommendation from this added experience, however, would be to enter the field in early fall e.g. mid-September--assuming the study is not season-dependent--and be prepared to conduct field activities for at least two months. Even so, changes in whale distribution, behavior, or other factors will still likely test those best plans. Nearing the end of the fall in any year, the humpbacks become more intent on social activities--male-male competition, males chasing females etc. By simply starting earlier, the chances are improved for eventually achieving success. Again, this might not be an option in some studies, and was not expected to be a problem in this study.

RELEVANCE OF THIS RESEARCH TO ONR

The original intent of developing, testing and applying the whale telemetry tag technology was of key importance to ONR goals of being able to assess impacts of underwater sounds on whales. Despite the studies' shortcomings, effective research tools were developed and completed which are appropriate for addressing the original impact assessment goals. Furthermore, these achievements in technology have significantly contributed to dozens of conservation, management, and academic initiatives for a multitude of endangered or threatened marine mammals both inside and outside of government, and inside and outside of the US. These contributions are ongoing, expanding in scope and have gone far outside of the marine realm. This research has also lead to several collaborative research efforts for example, in the spring and summer 1998, five right whales were tagged off Massachusetts with simpler (no sound recording) MST tags to provide baseline data in high vessel-use areas (Wiley and Goodyear 1998). Because of the demands for these systems, their development has continued and advanced significantly since the ONR funding period ended.

In keeping with ONR's objective to benefit the scientific community in the long-term from research they have supported, the technology developed in this research has been made available through a commercial outlet. H.A.B.I.T. Research, Ltd., a biotelemetry research and instrument manufacturing company was created which manufactures and sells MST tag systems and other instruments developed beyond the ONR grants. In particular, a state-of-the-art receiver was specifically designed to handle data telemetry from MST-type and other data logging tags. This new receiver has recently become available for sale. Secondly, reduction in size of the data logger electronics to about one-half the size used in the ONR studies has been made. These changes translate into significant overall tag size reduction which should improve field tagging and data collection success.